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In This Issue

"The price at which the market demand curve and market supply curve intersect is a market clearing price at which buyers and sellers are satisfied such that no economic forces are engaged to change the price." In their economics classes, multitudes of economics students have heard this explanation of price determination. Although this explanation is correct and it generically describes the interaction of market forces in determining prices, a student who tries to apply it to predict a price in a particular market quickly recognizes its limits. Where are the market demand curve and the market supply curve the instructor so easily sketched? Where is the market where these forces interact?

The gap between the theoretically sound explanation of price determination on textbook supply and demand schedules and the explanation of price determination as actual markets that represent not only different products but also the same product with differing time, space, and form attributes has always been imperfectly bridged. Both articles in this issue address the issue of price determination in a particular market.

In the lead article, Plato addresses the pricing of American options on commodity futures contracts. Recognizing that questions will inevitably arise about whether the market price of these recently permitted instruments lies above or below their real economic value, Plato describes a numerical procedure which provides unbiased estimates of the premiums for these contracts by accounting for the value of early option exercise.

In the following article, Brorsen, Grant, and Chavas investigate price discovery for rice byproducts and conclude rice byproduct prices may be more influenced by shifts in their demand than shifts in their supply.

In the Research Review, Schertz returns us to commodity options contracts and explores the relationship between the role of agricultural commodity options and Government price supports in transferring price risks from producers to a broader group in society, and Trechter reviews a set of writings, *Risk Management in Agriculture*.

GERALD SCHLUTER

Best Article Award

The ERS Administrator's Award for the best article in *Agricultural Economics Research* for the publication year ending April 1984 went to Laura A. Blanciforti, formerly of the National Economics Division. She was honored at a ceremony on February 12, 1985, for her excellence in creative economic analysis and communication in her article, "The Almost Ideal Demand System: A Comparison and Application to Food Groups."

Contents

Valuing American Options on Commodity Futures Contracts

By Gerald Plato*

Abstract

The author modified a numerical procedure developed by Cox, Ross, and Rubinstein for valuing options on stocks to value options on commodity futures contracts. The numerical procedure, unlike Black's widely used analytical approach, can include the value of early exercise in the option-premium estimates. Analysis with the numerical procedure shows that the variability in the underlying futures price is crucial in determining the value of an option.

Keywords

Commodity options, futures contracts, hedging

Introduction

Options on commodity futures contracts provide a new risk-management tool for the participants, including farmers, in the corresponding cash-commodity markets. The pricing accuracy of the markets for these options will be a crucial factor in determining their usefulness as a risk-management tool as well as their survival in the market place. Questions will inevitably arise about whether the market prices of these options lie above or below their real economic value. This article describes and evaluates a method for estimating the values of these options, illustrates its use, and examines the importance of the required parameters.

Asay (*1*), Figlewski and Fitzgerald (*5*), Gardner (*6*), Hoag (*8*), and Ramaswamy and Sundaresan (*13*) have examined the pricing of options on commodity futures contracts.[1] All but Ramaswamy and Sundaresan examined the pricing of European rather than American options. However, American options are being traded on U.S. exchanges.

A buyer of a European call option on a commodity futures contract can only exercise the right to buy a commodity futures contract, at the exercise price, on the option expiration date. Conversely, a buyer of a European put option can only exercise the right to sell on the option expiration date. A buyer of an American option on a commodity futures contract has the additional right of exercising the option on any date prior to the expiration date. The privilege of exercising early increases the price of an option by giving the buyer the right to immediately realize profits equal to the difference between the exercise price and the futures price. Profits from early exercise are taken only when it is advantageous to the option buyer. A major objective of this article is to examine the effect of the right of early exercise on the price of options on commodity futures contracts.

Relatively little attention has been given to put options in the recent literature on pricing options on commodity futures contracts. Gardner's article is the only one that emphasizes put options (*6*). Put options for farmers and storers are a substitute for taking a short position in a futures market in expectation of a later sale in the corresponding cash markets. Short selling in commodity futures markets is a major use of these markets by the participants in the corresponding cash market. Therefore, put options on commodity futures contracts have considerable potential value to many cash-market participants. This ar-

*The author is an agricultural economist with the National Economics Division, ERS. Richard Heifner and Douglas Gordon provided valuable assistance in the preparation and review of this article. Many constructive criticisms were also received from Gerald Schluter, Roger Conway, and anonymous reviewers.

[1]Italicized numbers in parentheses refer to items in the references at the end of this article.

ticle examines the pricing of put options, which appear to especially interest farmers, as well as call options on commodity futures contracts. Recent publications by Paul, Heifner, and Gordon (*12*) and by Kenyon (*10*) describe alternative ways that farmers and other hedgers can use these new option markets.

The first section of this article reviews relevant parts of option pricing theory and describes a procedure for calculating the expected price or premiums of American options on commodity futures contracts. The second section illustrates the procedure for soybeans, examines the effect of the right of early exercise on option price, and examines the importance of futures price variability and the interest rate in determining option prices.

Aspects of Option Pricing Theory

Similar procedures apply in estimating the value of options, both puts and calls, on stocks, physical commodities, and commodity futures contracts. For example, the numerical procedure or algorithm derived by Cox, Ross, and Rubinstein for calculating the price of call and put options on stocks, both American and European, can be used to calculate prices of American and European options on commodity futures contracts (*4*). Their algorithm can also be used to calculate American and European option prices on physical commodities.

Option-pricing theory is based on the concept of the perfect or riskless hedge. This hedge involves simultaneous and offsetting positions in an asset, for example, a stock, physical commodity, or commodity futures contract, and an option on the asset. One can make the hedge riskless by maintaining the ideal or perfect ratio of asset units to option units. This perfect hedge ratio balances gains on the asset position with losses on the option position or losses on the asset position with gains on the option position. Because the hedge is riskless, the equity or amount invested in the hedge is specified as earning the riskless rate of return.[2]

Gains and losses on the option are a function of the level of the asset price and the time remaining until the option expires. Therefore, to keep the hedge riskless, the ratio of units of the asset to the units of options must be continually readjusted.

The method used in this article to calculate option prices on commodity futures contracts is based on the concept of the riskless hedge.

The following equation represents the perfect or riskless hedge between a call option on a stock and the stock over the time interval Δt (*9*):

$$H\Delta S_{\Delta t} - \Delta C_{\Delta t} + HDS_t = r(HS_t - C_t) \tag{1}$$

where:

H = hedge ratio (number of stock shares per call option in the riskless hedge),

$\Delta S_{\Delta t} = S_{t+1} - S_t$ = change in stock price over the time interval Δt,

S_t = stock price at beginning of time interval Δt,

$\Delta C_{\Delta t} = C_{t+1} - C_t$ = change in call option price over time interval Δt,

C_t = call price at beginning of time interval Δt,

D = dividend rate ($D \geq 0$),

r = riskless interest rate over the time interval Δt, and

$HS_t - C_t$ = equity in riskless hedge.

Equation (1) says that the net change in the value of the call option-stock combination over the time interval Δt plus any dividends equals the riskless rate of return on the equity in the combined position. As implied by the right side of equation (1), the equity in the riskless hedge consists of a long position in the stock and a short position in the call option.[3] Call op-

[2]Hedging involves simultaneous and offsetting positions in two markets. Simultaneous and offsetting positions in a cash market and the corresponding futures market is a common method of hedging in agricultural markets.

[3]The plus signs in equation (1) indicate a long position and the negative signs a short position. This convention is maintained throughout this article.

tion price changes move in the same direction as the stock price changes. Therefore, opposite positions in the call option and stock are needed to make the hedge riskless.

The ratio of stock to options must be adjusted at the end of the time interval Δt to keep the hedge riskless for the next time interval. The reason is that the change in the option price depends on the level of the stock price and the time remaining until option expiration.

Black and Scholes derived a differential equation for describing the value of a call option on a nondividend stock (*3*). Their derivation uses an equation similar to equation (1) with the dividend, D, equal to zero.

Black used the same procedure later to derive a differential equation for describing the value of a call option on a commodity futures contract (*2*). His derivation uses an equation similar to equation (2) which describes a riskless hedge involving call options on commodity futures contracts and commodity futures contracts:

$$H(-\Delta S_{\Delta t}) + \Delta C_{\Delta t} = rC_t \tag{2}$$

The variables and parameters in equation (2) are as defined in equation (1) except that they refer to commodity futures contracts instead of to shares of stock. New variable and parameter names were not used because one can use equation (1) to calculate call option prices on commodity futures contracts; in this situation the variables and parameters in equation (1) refer to futures contracts. The context of the discussion shows when the variables and parameters refer to commodity futures contracts and when they refer to stock.

Equation (2) says that the net change in the value of the call option-futures combination over the time interval Δt equals the riskless rate of return on the equity in the hedge. The equity in this hedge equals the value of the call option. The value of a futures position is zero at the beginning of the time interval Δt.[4] Therefore, the level of the futures price is omitted from equation (2). Equation (2) contains the call option long and the futures position short, the opposite of the call option and stock positions in equation (1).

Black recognized that his differential equation for a call option on a commodity futures contract derived from equation (2) has the same solution for the price of the call option as Merton's differential equation for a call option on a stock when the stock pays dividends at the riskless rate. Merton's differential equation can be derived from the riskless hedge in equation (1) (*11*). That identical call option prices occur can be seen if one sets $D = r$ in equation (1) which, after simplifying, produces equation (2).[5]

Equation (3) describes the riskless hedge between a put option on a stock and the stock over the time interval Δt:

$$H\Delta S_{\Delta t} + \Delta P_{\Delta t} + HDS_t = r(HS_t + P_t) \tag{3}$$

P_t is the value of the put option at the beginning of the time interval Δt, and $\Delta P_{\Delta t}$ is the change in value of the put option over this interval. The other variables and the parameters in equation (3) are the same as those in equation (1). The major difference between equations (3) and (1) is that the riskless hedge in equation (3), $HS_t = P_t$, contains long positions in both the stock and put option. A change in the stock price moves the put price in the opposite direction. Therefore, long positions are needed in both the put and the stock to make the hedge riskless.

Equation (4) describes the riskless hedge between a put option on commodity futures and commodity futures over the interval Δt:

$$H\Delta S_{\Delta t} + \Delta P_{\Delta t} = rP_t \tag{4}$$

The variables are the same as those in equation (2) except that the put option, P_t, replaces the call option, C_t. As in the case of call options on commodity futures contracts, the level of the futures price is omitted because the current value of the futures

[4]Black assumed that the current futures price equals the expected futures price at contract expiration (*2*). The current value of a futures position is zero under Black's assumption regardless of any previous gains or losses.

[5]Cox, Ross, and Rubinstein and also Jarrow and Rudd show stock dividend payments based on ending period stock prices, HDS_{t+1}, rather than on beginning period stock prices, HDS_t (*4, 9*). Equations (1) and (2) with $D = r$ are not equal except in the limit as the time interval, Δt, approaches zero when the dividend payments are based on ending period futures prices.

position is assumed to be zero. Long positions are held in both the put and futures to make the hedge riskless because put-price changes move in the opposite direction from the futures-price changes.

The put-option price in equation (3) when $D = r$ is the same as the put-option price in equation (4). This can be seen if one sets $D = r$ in equation (3) and simplifies it to produce equation (4). This result is the same as that for call-option prices in equations (1) and (2) when $D = r$ in equation (1). The equivalency of option prices in equations (1) and (2) and in equations (3) and (4) when $D = r$ is the reason that the Cox, Ross, and Rubinstein algorithm for valuing stock options can also be used for valuing options on commodity futures contracts (*4*).

Differential equations derived from the preceding equations for describing the relationship of options to stock and to commodity futures contracts can be solved analytically if the options are European.[6] If the options are American, then analytical solutions are possible only when early option exercise is never desirable. However, exercising American put and call options on commodity futures contracts prior to the expiration date is sometimes desirable as is shown in the analysis.

The advantage of the Cox, Ross, and Rubinstein algorithm over the analytical approach to calculating option prices is that it can handle the early exercise of American options. If the dividend rate is set equal to the riskless interest rate, then their algorithm can also estimate prices for call and put options on commodity futures contracts, both American and European. We now briefly describe how this algorithm calculates the call-option price in equation (1) and also the call-option price in equation (2) when the dividend rate is set equal to the riskless interest rate. We also discuss the modifications for calculating put-option prices.

Economists Cox, Ross, and Rubinstein, following Black and Scholes, assume that the stock price change from the current time until the option expiration date is log normally distributed. They take advantage of the fact that the log normal distribution can be approximated as the product of a large number of binomial changes. Their algorithm enumerates these binomial changes backwards through time from the option expiration date. This procedure allows all possible stock prices and corresponding option prices to be determined prior to each binomial price change.

The Cox, Ross, and Rubinstein algorithm first divides the time remaining until option expiration into T equal intervals where t is the beginning and $t+1$ the end of the t^{th} interval. T is set arbitrarily, but as its value is increased the approximation to the log normal distribution is improved. The option matures or expires on $T+1$ which is the end of interval T, the last interval.

The stock price from the beginning to the end of each time interval is specified as moving up or down according to the multiplicative binomial distribution where the price at the end of an interval is $S^u_{t+1} = uS_t$ or $S^d_{t+1} = dS_t$ for a price increase and a price decrease, respectively. The parameters u and d are the possible outcomes from this bionomial probability distribution over the t^{th} interval.

The algorithm next calculates all the possible stock prices on the option's expiration date using the possible outcomes from the multiplicative binomial distribution from the beginning of the first interval, $t = 1$, to the expiration date, $t = T+1$. The possible stock prices when the option expires are represented by j equals 0 through T in equation (5).

$$S_{T+1,j} = u^{T-j}d^jS_1, \qquad \text{for } j = 0,1,\ldots,T \tag{5}$$

where:

$T - j$ = number of stock price increases,

j = number of stock price decreases, and

S_1 = stock price at the beginning of first time interval.

We can then use the stock prices to calculate all the possible option prices, call or put, on the expiration date as shown below.

For calls:

$$C_{T+1,j} = \text{Max}(0, S_{T+1,j} - K), \text{ for } j = 0, 1,\ldots, T$$

For puts:

$$P_{T+1,j} = \text{Max}(0, K - S_{T+1,j}), \text{ for } j = 0, 1,\ldots, T$$

[6]Asay discusses the relationships among the analytical solutions to these differential equations for European call options on stocks, commodity futures contracts, and physical commodities (*1*).

The exercise price, K, is the stock purchase price for a call option and the stock selling price for a put option.

The algorithm's next step is to calculate all the possible stock prices at T, the beginning of the last time interval. Here the stock prices are calculated as before except that $T-1$ replaces T and T replaces $T+1$ in equation (5). Next, we calculate the option prices at the beginning of the last time interval.

We now explain the procedure for calculating each of these option prices. The time subscripts are in terms of the typical time interval, t, because the procedure for calculating option prices is the same for the beginning of each time interval.

We derive equation (6) by adding the equity in the riskless hedge for call options on stocks, $HS_t - C_t$, to both sides of equation (1).

$$HS_{t+1} - C_{t+1} + HDS_t = (r + 1)(HS_t - C_t) \qquad (6)$$

Equation (6) shows that the net value of the stock and call option positions plus the dividend at the end of the current time interval equals the original equity in the hedge increased at the riskless interest rate. In this formulation, the equity in the riskless hedge is equivalent to a riskless bond over the interval t to $t+1$. Thus equation (6) can be rewritten as:

$$HS_{t+1} + HDS_t - C_{t+1} = (r + 1)B \qquad (7)$$

where $B = HS_t - C_t$ and B is a riskless bond worth $(r+1)B$ at $t+1$. The stock price, S_{t+1}, given S_t, can have two possible values because the stock price is specified as following the multiplicative binomial distribution. The two stock price outcomes given S_t are shown in the following two equations:

$$HS^u_{t+1} + HDS_t - C^u_{t+1} = (r + 1)B \qquad (8)$$

$$HS^d_{t+1} + HDS_t - C^d_{t+1} = (r + 1)B \qquad (9)$$

where:

S^u_{t+1} = price after upward movement,
S^d_{t+1} = price after downward movement,
C^u_{t+1} = option price associated with upward stock price movement, and
C^d_{t+1} = option price associated with downward stock price movement.

At this point the values of the stock prices and call option prices shown in the preceding list have been previously calculated. The algorithm next solves equations (8) and (9) simultaneously for H and B. Because $B = HS_t - C_t$, C_t can easily be calculated because the stock price, S_t, is already known.[7]

If the value of exercising the option immediately is greater than the value found by use of the preceding equations, then the value of an American option at the beginning of the t^{th} time interval is the immediate exercise value. The immediate exercise value is $S_t - K$ for calls and $K - S_t$ for puts where S_t is the price at the beginning of the t^{th} time interval and K is the exercise price. This last step is omitted for European options.

Next, the algorithm uses the option prices just calculated for the beginning of interval T to calculate the option prices for the beginning $T-1$. The procedure is the same as described for using the option prices at $T+1$ to calculate the option prices at the beginning of interval T. The algorithm continues by calculating all the option prices for the beginning of the previous time interval using the option prices calculated for the beginning of the current interval. This procedure is continued until the option price for the beginning of the first time interval is calculated.

The Cox, Ross, and Rubinstein algorithm can be modified to solve the price of American options on commodity futures contracts without resorting to solving for the value of a stock option with the dividend rate set equal to the riskless interest rate. The modification involves replacing equations (8) and (9) that describe the value of a call option on a stock with equations that describe the value of a call option on a commodity futures contract.

We derive equation (10) by adding the equity in the riskless hedge for call options on commodity futures contracts, C_t, to both sides of equation (2):

$$H(S_t - S_{t+1}) + C_{t+1} = (r + 1)C_t \qquad (10)$$

This equation says that the change in the value of the futures position over the t^{th} time interval plus

[7]One can derive a set of simultaneous equations for put options on stocks from equation (3) using the procedures shown for deriving the simultaneous equations for calls in (8) and (9) from equation (1). The simultaneous equations for puts can be solved for the ratio of stocks to put options, H, and for the price of the put option, P_t.

the value of the call position at the end of this interval equals the equity in the riskless hedge increased at the riskless interest rate.[8] As in the stock option case shown in equation (6), S_{t+1} given S_t can have two values as shown in equations (11) and (12).

$$H(S_t - S^u_{t+1}) + C^u_{t+1} = (r + 1)C_t \qquad (11)$$

$$H(S_t - S^d_{t+1}) + C^d_{t+1} = (r + 1)C_t \qquad (12)$$

The value of the equity in the riskless hedge, C_t, can also be thought of as equivalent to a riskless bond, B, that is worth (r + 1)B at the end of the t^{th} time interval. One can find the value of the call, C_t, by solving the preceding two equations simultaneously for C_t and H. These equations produce the same call value as equations (8) and (9) when the dividend rate is set equal to the riskless interest rate.[9]

The solutions for C_t and H in equations (11) and (12) are shown in equations (13) and (14).

$$C_t = [(1 - d)/(u - d)C^u_{t+1} + (u - 1)/(u - d)C^d_{t+1}]/(r + 1) \qquad (13)$$

$$H = (C^u_{t+1} - C^d_{t+1})/(d - u)S_t \qquad (14)$$

A computer program for calculating prices of American options on commodity futures contracts is shown in the appendix. The program is based on the preceding explanation. It is written in Microsoft Basic and was implemented on an IBM Personal Computer.

Estimates of the Value of American Options on Soybean Futures Contracts

The analysis includes an examination of (1) the right or early exercise on the price of options on commodity futures contracts, and (2) the sensitivity of option prices to the variability of the underlying futures price and to the level of the riskless interest rate. I will describe the parameters used in the algorithm to calculate soybean option prices before presenting the analysis.

Description of the Parameters

One needs values of u and d in equation (5) to implement the algorithm described in the previous section to calculate the prices of options on commodity futures. Cox, Ross, and Rubinstein showed that:

$$u = e^{\sigma\sqrt{tau/T}} \qquad (15)$$

$$d = e^{-\sigma\sqrt{tau/T}} \qquad (16)$$

where σ is the standard deviation of the rate of change in the stock or futures price for 1 year, tau is the fraction of a year until the option expires and is partitioned into T equal time intervals.

Table 1 shows estimates of the standard deviation of the daily rate of change in the closing futures price. I chose the November and March soybean futures contracts to examine option prices during the growing season when supplies are frequently scarce and option prices after harvest when supplies are usually plentiful. Gordon found that the variability of futures price changes for crops is generally highest during the growing season (7). The estimates in table 1 agree with this finding.

Table 1—Estimated standard deviations in the daily rate of change in the closing soybean futures price

Crop year	Futures contract[1]	
	November	March
1983	0.0220	0.0115
1982	.0111	.0079
1981	.0139	.0107
1980	.0185	.0198
1979	.0178	.0156
1978	.0137	.0118
1977	.0231	.0125
1976	.0218	.0155
1975	.0206	.0097
1974	.0223	.0207
1973	.0378	.0192

[1]November estimates are based on daily closing prices from June 1 to October 15, and March estimates on daily closing prices from November 1 to February 15.

[8]One can rewrite the terms inside the first parenthesis as $-(S_{t+1} - S_t)$ or $-\Delta S_{\Delta t}$ and interpret as minus the change in the futures price over the time interval Δt. The preceding minus signs designate a short futures position.

[9]One can derive a set of simultaneous equations for put options on commodity futures from equation (4) using the procedures shown for deriving the simultaneous equations for calls in (11) and (12) from equation (2). The simultaneous equations for puts can be solved for the ratio of commodity futures contracts to put options on commodity futures contracts, H, and for the price of the put option, P_t.

Two findings implied that one should make a large number of estimates to understand the significance of the variability of the soybean futures price on option prices. First, preliminary estimates of option prices using the option pricing algorithm suggested that option prices are highly sensitive to the underlying variability of the soybean futures price. Second, the initial estimates for the 1982 and 1983 crop years suggested that the daily variability of the soybean futures price may vary considerably among crop years.

The analysis primarily uses the variability estimates for the 1982 and 1983 crop years. The estimates in table 1 suggest that this choice provides both a high variability year and a low variability year for the soybean futures price. I examined the sensitivity of option prices to soybean price variability using changes in price variability from the 1982 and 1983 levels.

I made the estimates in table 1 by taking the natural logs of the daily closing prices and then calculating the standard deviation of the first differences of the natural logs. The estimates for the November futures contract are based on daily prices from June 1 to October 15. The first date represents a typical soybean planting date and the second date the option expiration date on the November futures contract. The estimates for the March contract were based on daily prices from November 1 to February 15. The first date represents a date on which most of the current harvest is completed, and the second date represents the option expiration date on the March futures contract.

An estimate of the riskless interest rate is also needed to implement the algorithm. The estimates used in the analysis are shown in table 2. I calculated these estimates from the bid and asked discount rates for U.S. Treasury bills. I chose the current and expiration dates on the Treasury bills to correspond with the beginning and expiration dates of the four cases shown in table 2. Estimates of the riskless interest rate were only calculated for the 1982 and 1983 crop years as preliminary analysis showed that option prices are much less sensitive to the interest rate than to the variability of the futures price.

Table 2—Estimated futures price variability and riskless interest rate and specifications of option time periods used in calculating option prices on commodity futures contracts

Case[1]	Futures contract option period	tau[2]	Futures variability		Annualized riskless interest rate[4]
			Daily	Annualized[3]	
		Months/year	*Standard deviation*		*Percent*
I	November 82 June 1-Oct. 15	4.5/12	0.0111	0.1755	12.80
II	November 83 June 1-Oct. 15	4.5/12	.0220	.3479	9.33
III	March 83 Nov. 1-Feb. 15	3.5/12	.0079	.1249	8.56
IV	March 84 Nov. 1-Feb. 15	3.5/12	.0115	.1818	9.14

[1]The case numbers designate combinations of times remaining until option expiration, standard deviations of the rate of change in the soybean futures price, and riskless interest rates used in calculating the option prices shown in table 3 and in figures 1 and 2.
[2]Time remaining until option expiration.
[3]The annual standard deviations of the rate of change in the soybean futures price were calculated by multiplying the estimated daily standard deviations by the square root of 250; a year was assumed to contain 250 trading days.
[4]The annual riskless interest rates were calculated from the average of the bid and asked discount rates for U.S. Treasury bills on June 1, 1982, and 1983, and on November 1, 1982, and 1983. The maturity dates were chosen to correspond with the option expiration dates for November and March options.

Table 2 also shows the four combinations of futures price variabilities and interest rates used in the analysis. The values of tau, or fraction of a year remaining until option expiration, are also shown in table 2. The accuracy in calculating option prices is determined in part by the number of time intervals, T, used in partitioning tau. A value of T equal to 75 was chosen. This selection is discussed further in the analysis.

The Analysis

Table 3 shows estimated American and European option premiums and hedge ratios for exercise prices at and close to the assumed $8 per bushel soybean futures price. The case or parameter descriptions for these estimates are provided in table 2.

An important result in table 3 is that American and European option prices are essentially the same when the exercise price is within 50 cents per bushel of the current futures price. The American option prices were at most only 9/10 of a cent above their European counterparts.

The largest premium differences between American and European options in table 3 occur at the $8.50 exercise price for the puts and at the $7.50 exercise price for the calls. American options in these two situations in table 3 have the largest probability of early exercise because the $8 futures price is closest to the level at which early exercise occurs. The $8 futures price is farthest from the level at which ear-

Table 3—Estimated premiums and perfect hedge ratios for American and European put and call options on soybean futures with exercise prices ranging from ± $0.50 from an assumed $8 futures price

Exercise price	Option premiums and hedge ratios[1]							
	Case I		Case II		Case III		Case IV	
	Amer.	Eur.	Amer.	Eur.	Amer.	Eur.	Amer.	Eur.
Puts:								
$8.50	0.638 (.68)	0.629 (.67)	0.955 (.56)	0.947 (.55)	0.548 (.80)	0.543 (.79)	0.622 (.71)	0.617 (.70)
$8.25	.472 (.58)	.466 (.57)	.800 (.51)	.794 (.50)	.360 (.66)	.358 (.65)	.450 (.60)	.447 (.59)
$8.00	.332 (.466)	.329 (.46)	.663 (.45)	.659 (.44)	.212 (.48)	.211 (.48)	.308 (.47)	.306 (.47)
$7.75	.219 (.35)	.217 (.35)	.536 (.39)	.532 (.39)	.108 (.30)	.108 (.30)	.195 (.35)	.194 (.35)
$7.50	.135 (.25)	.134 (.24)	.426 (.33)	.423 (.33)	.046 (.16)	.046 (.16)	.115 (.24)	.114 (.23)
Calls:								
$8.50	.152 (.29)	.151 (.29)	.466 (.42)	.463 (.42)	.055 (.19)	.055 (.19)	.130 (.28)	.130 (.28)
$8.25	.229 (.39)	.227 (.39)	.556 (.47)	.552 (.47)	.114 (.33)	.114 (.33)	.204 (.39)	.203 (.39)
$8.00	.332 (.51)	.329 (.50)	.663 (.53)	.659 (.52)	.212 (.51)	.211 (.50)	.308 (.51)	.306 (.47)
$7.75	.462 (.62)	.456 (.61)	.780 (.59)	.774 (.58)	.354 (.68)	.352 (.68)	.441 (.64)	.438 (.63)
$7.50	.621 (.73)	.612 (.71)	.915 (.65)	.907 (.64)	.540 (.83)	.535 (.82)	.607 (.75)	.602 (.74)

[1]The four cases are explained in table 2 and the accompanying text. The perfect hedge ratios are shown in the parentheses.

ly exercise occurs for puts at the $7.50 exercise price and for calls at the $8.50 exercise price. In these two situations, the probability of early exercise is the smallest in table 3, and the price increments of American over European options are the smallest. The maximum price difference in these two situations is 3/10 of a cent. The difference is less than 1/10 of a cent for case III.

The small premium differences between American and European options in table 3 suggest that Black's analytical approach to valuing European options provides a close approximation to valuing American options for exercise prices near the current futures price (2).

The perfect hedge ratios also differ little between the American and European options in table 3. As explained previously, the hedge ratio is the ratio of futures contracts to options contracts, and the perfect hedge ratio keeps the combination of futures and options riskless for the current time period, t to t + 1. That the hedge ratios differ little between the American and European options in table 3 is to be expected because their prices differ little.

I used Black's approach to determine a suitable number of intervals, T, in which to partition the time to option expiration, tau. Black's approach is equivalent to specifying an infinite value for T. The procedure was to compare European option prices from the algorithm with those from Black's approach for the four cases in table 3 at the $8 exercise price. Comparisons showed that with T equal to 75 the algorithm estimates were from 7/100 to 21/100 of a cent more than with Black's approach. One can attain additional accuracy by specifying a larger value for T. However, T equal to 75 provides sufficient accuracy to satisfy the objectives of this study.

The European put and call option prices for each case in table 3 are equal when both the exercise and futures prices equal $8 per bushel. This result is in accord with the put-call parity theorem derived by Stoll:

$$C_t - P_t = e^{-R(tau)}(S_t - K) \tag{17}$$

which shows that the call price, C_t, equals the put price, P_t, when the futures price, S_t, and the exercise price, K, coincide (*14*).[10] The put-call parity relationship in equation (12) also applies at each of the other exercise prices for the European options for each case in table 3. The put-call parity theorem does not hold exactly for American options. However, it does closely approximate the relationship of American put and call option prices in table 3.

I examined the influence of futures price variability by estimating option prices for cases II and IV after increasing the standard deviation of the futures price by 1 percent for these two cases. I then calculated percentage changes in the option prices from those originally estimated for cases II and IV. I also used the same procedure to examine the influence of a 1-percent increase in the interest rate on option price.

The results showed that the option price is highly sensitive to the variability of the futures price and insensitive to the interest rate. The 1-percent increase in the standard deviation of the futures price increased the option prices in cases II and IV from 0.4 to 2.0 percent. Each option price is increased because the probabilities of large favorable changes in the futures price are increased.

The 1-percent increase in the interest rate decreased each of these same option prices by less than 0.03 percent. Option prices are decreased by the larger discounting in equation (13).

There is considerable interest in the cost of put options for hedging the production outcome over the growing season. American put option prices for a growing season's production hedge were estimated to be 33.2 and 66.3 cents per bushel at the $8 exercise price for cases I and II, respectively. These option prices are 4.2 and 8.3 percent of the $8 per bushel soybean futures price.

Investigating the influence of the interest rate leads one to suspect that the put option price differences between cases I and II are largely due to the difference in futures price variability. I confirmed this suspicion by switching the interest rate in cases I and II and reestimating the option prices. Using the

[10]R equals the annualized interest rate (table 2).

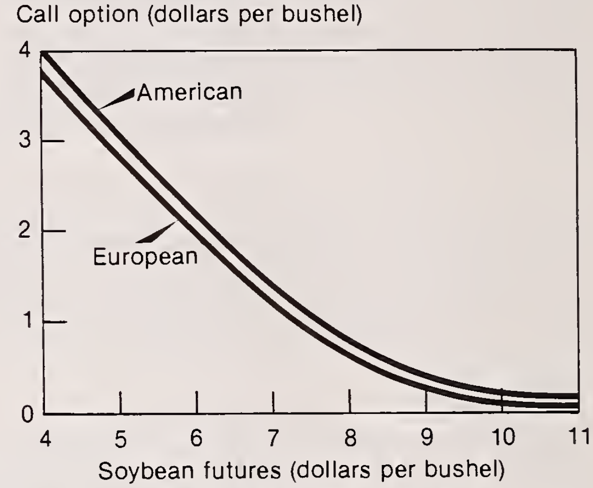
case II interest rate in case I increased the put option prices by at most only 0.9 percent. Using the case I interest rate in case II decreased the put option prices by at most only 1 percent.

Richard Heifner, in a personal communication, has suggested that the ratio of the option price to the futures price is determined by the ratio of the exercise price to the futures price. For example, using futures and exercise prices of $6 rather than $8 in cases I and II also produces put option prices that are 4.2 and 8.3 percent of the futures price, respectively.

Cases I and II were chosen to represent growing seasons with low and high futures price variabilities. Therefore, the ratios of the put option to futures prices for cases I and II provide estimates of those expected in low and high variability years regardless of the actual futures price level. This conclusion is based on the small influence of the interest rate on option price and on the finding that the ratio of option to futures price is determined by the ratio of exercise to futures price.

Figure 1

Premiums for American and European Put Options on Soybean Futures Contracts[1]



[1]Exercise price is $8 per bushel, soybean futures range from $4 to $11 per bushel, and Case II assumptions apply (table 2).

The distance of the European curve from the American curve is not drawn to scale.

Figure 1 compares the prices of American and European put options for soybean futures prices between $4 and $11 per bushel for case II. The exercise price is $8 per bushel. Figure 1 draws out the price difference between American and European options when the exercise price is not close to the futures price.

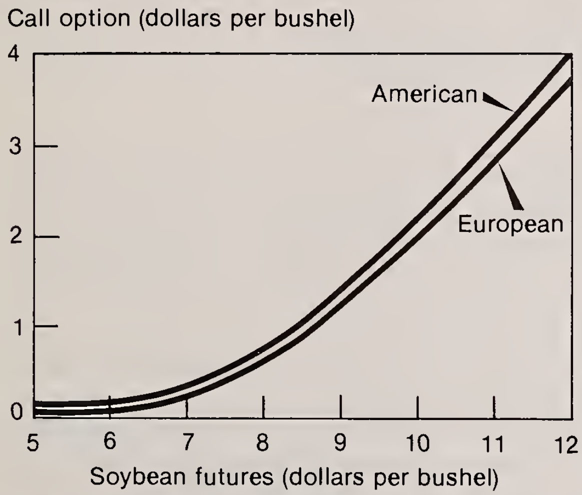
The American put option price increases relative to the European put option price as the soybean futures price decreases. For example, as the futures price decreases from $8 to $5.25, the price of the American option rises from about 0.5 to 8 cents per bushel relative to its European counterpart. This relative price increase for the American option reflects the increasing probability that it will be exercised prior to the expiration date. For all futures prices below $5.25 per bushel, the optimal decision is to exercise immediately. The slope of the American put-option curve below $5.25 is minus 1. As shown in figure 1, the American curve approaches the European curve as the soybean futures price increases above $8 per bushel. This result reflects the decreasing probability that the American put option will be exercised prior to expiration. Although not shown, each curve approaches a zero slope and the horizontal axis as the futures price rises above $11.

Figure 2 compares the prices of American and European call options for soybean futures between $5 and $12 per bushel for case II. The exercise price is $8 per bushel. As in the previous figure, one can draw out price differences between American and European options when the exercise price is not close to the futures price.

The price of the American call option price increases relative to its European counterpart as the soybean futures price increases. For example, as the futures price increases from $8 to $12 per bushel, the price of the American call option rises from about 0.5 cent to about 11 cents per bushel relative to its European counterpart. As in the put-option comparison, this relative price increase reflects the increasing probability that the American call option will be exercised before the expiration date. For all futures prices above $12 per bushel, the optimal decision is to exercise immediately. The slope of the American option curve is plus one above the $12 futures price. As shown in figure 2, the American curve approaches the European curve as the futures price decreases below $8 per bushel. This result reflects the decreasing probability that the American call option will be exercised prior to expiration. Although not shown, each curve approaches a zero

Figure 2

Premiums for American and European Call Options on Soybean Futures Contracts[1]



[1] Exercise price is $8 per bushel, soybean futures range from $5 to $12 per bushel, and Case II assumptions apply (table 2).

The distance of the European curve from the American curve is not drawn to scale.

slope and the horizontal axis as the futures price decreases below $5.[11]

Early exercise is frequently complicated for hedgers because the timing of hedge removal is frequently dictated by business circumstances. For example, a farmer using a put-option production hedge for soybeans would not generally remove the hedge until the crop is harvested even when the soybean futures price falls sufficiently for the option to be exercised early. However, a farmer in this situation might choose to gain immediate access to the funds in the put option position while maintaining a hedge against further price declines. The farmer can do so by exercising the put option and buying another with the same expiration date but with an exercise price equal to the current lower futures price.

American put option prices are more than 3 cents per bushel higher than their European counterparts when the soybean futures price is more than $2 below the exercise price (fig. 1). Conversely, American call option prices are more than 3 cents per bushel higher than the European option prices when the soybean futures price is more than $2 above the exercise price (fig. 2). Put and call options are referred to as being deep in the money in this situation. Most option hedges are placed at exercise prices close to the current futures price. In this situation, American and European options have essentially the same prices (table 3). However, an option may be deep in the money when an option is lifted or removed prior to expiration. In this situation, American options provide a larger return to hedgers. The higher returns for American options stem from the ability to gain immediate access to the funds represented by the difference between the futures price and the exercise price. Access to these funds for European options is delayed until the expiration date.

This advantage is examined by simulating hedge removal based on American and European options that are close to their expiration dates. Option hedges will generally be based on contracts that expire close to the future date of intended cash market transaction. There is no need to pay for price protection beyond that date.

I compared American and European options for two hedge removal situations:

> Removal of a put option production hedge on the November futures contract on October 1 using the case II futures price variability and interest rate; this date is 1/2 month prior to option expiration on the November futures contract.
>
> Removal of a put option storage hedge on the March futures contract on January 15 using the case IV futures price variability and interest rate; this date is 1 month prior to option expiration on the March futures contract. The options have an $8 exercise price.

On October 1, the American and European put option prices are estimated to be $1.50 and $1.495 per bushel, respectively, if the soybean futures price falls to $6.50 per bushel. In this situation, the American put option provides a $25 larger return on a 5,000-bushel options contract. On January 15, the American and European put options are estimated to be $1.50 and $1.489 per bushel. In this situation, the American put options provides a $55 larger return on a 5,000-bushel options contract.

[11] The hedge ratios, like those shown in table 3, are equal to the absolute value of the slope of the appropriate option price-soybean price curve. The absolute values of these slopes range from 0 to 1.

The ratio of the American to European option prices in each case equals 1 plus the riskless rate of return that can be earned over the time remaining until option expiration. This result means that the difference between the American and European option prices in each case represents the opportunity costs of not being able to exercise the European option immediately to gain access to the difference between the futures price and the exercise price. The opportunity costs are relatively small in the two hedge-removal examples since only 1/2 month and 1 month remain until option expiration.

The strategy of exercising or selling put options early to receive funds immediately and maintaining the hedge by buying another put option at a lower exercise price may offer a means of increasing the returns from hedging with put options. Similarly, exercising or selling a call option early and buying another at a higher exercise price may also offer a means of increasing the returns from hedging with options. However, examination of this strategy requires detailed budgeting of an individual's business situation and is beyond the scope of this article. As figures 1 and 2 suggest, American options can sometimes provide considerably higher returns than European options with this strategy.

Conclusions

I have described and evaluated a method for estimating premiums for options on commodity futures contracts which takes into account the value of early exercise. In the examples examined, this method produced premium estimates only slightly larger than Black's formula when the futures price is close to the exercise price. However, Black's formula may undervalue premiums for American options deep in the money by as much as the percentage represented by the riskless interest rate over the time remaining until option expiration. For example, for an option deep in the money with 3 months until expiration, the undervaluation by Black's formula can be as much as the percentage available on U.S. Treasury bills that also mature in 3 months.

The algorithm used in this article has several advantages over Black's formula beyond its ability to include the value of early exercise. It can include the effects of a support price on the price of a put option by limiting maximum future values of the option to the exercise price minus the support price. It can also include changes in the level of futures price variability over the period prior to option expiration. A recent study by Gordon indicates that the variability of futures prices generally increases toward the end of futures contracts (7).

The analysis suggests that the prices of options on commodity futures contracts are sensitive to the variability of futures prices and insensitive to the interest rate. These results imply that considerable effort is needed to estimate futures price variability before evaluating the market prices of these options.

The analysis of futures price variability in this article is entirely after the fact. However, the market prices of options on commodity futures contracts reflect prior market estimates or expectations of variability. One interesting area of investigation is to examine the likely factors that influence market expectation of future price variability. A likely candidate for this investigation is the level of market stocks.

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Appendix

```
10 REM  Program for Calculating Prices of
        American Put Options
20 REM  on Commodity Futures Contracts
30 REM  (see 940 through 970 for modifying the
        program to
40 REM  calculate call option prices; see 980 for
        modifying
50 REM  the program to calculate European option
        prices)
60 REM
70 DIM PUTT (100), SAVEPUT (100)
80 READ S, K, R, T, TAU, SIGMA
90 LPRINT, S, K, R, T, TAU, SIGMA
100 REM
110 REM  Calculate riskless interest rate for one
         time interval, RR
120 REM
130 RR = (1. + R)^(TAU/T)
140 RR = RR-1!
150 REM
160 REM  Calculate one plus the rate of futures
         price increase, U,
170 REM  and decrease, D, respectively, over one
         time interval
180 REM
190 U = EXP (SIGMA*((TAU/T)^.5))
200 D = EXP (-SIGMA*((TAU/T)^.5))
210 LPRINT RR, U, D
220 JJJ = T+1
230 IX = JJJ-1!
240 IY = O!
250 REM
260 REM  For loop 290 to 380 calculates all possible
         put option prices
270 REM  on the expiration date
280 REM
290 FOR I = 1 TO JJJ
300 RATE = (U^IX)*(D^IY)
310 PRICE = S*RATE
320 PUTT (I) = K-PRICE
330 IF PUTT (I),<O! THEN PUTT (I) = O!
340 PRINT PUTT (I), PRICE, RATE, JJJ, I, IX, IY
350 IY = IY+1
360 IX = IX-1
370 SAVEPUT (I) = PUTT (I)
380 NEXT I
390 JJJ = JJJ-1
400 IX = JJJ-1
410 IY = O
420 PRINT JJJ
430 REM  For loop 450 to 690 calculates all possible
         put option prices
440 REM  for the beginning of the current time
         interval
450 FOR I = 1 TO JJJ
```

```
460 RATE = (U^IX)*(D^IY)
470 PRICE = S*RATE
480 II = I+1
490 REM
500 REM The following two equations calculate a
        tentative option price
510 REM and hedge ratio (these equations corres-
        pond with equations 13
520 REM and 14 in the text)
530 REM
540 PUTT (I) = (((1! - D)/(U - D))*SAVEPUT (I)
               + ((U - 1!)/(U - D))*SAVEPUT (II)/
               (RR + 1!)
550 H = (SAVEPUT (I) - SAVEPUT (II)/
        ((D - U)*PRICE)
560 REM Calculate value of exercising immediately
570 REM
580 TEST = K-PRICE
590 REM Put option price equals exercise value
        when it is greater than
600 REM or equal to the value calculated in state-
        ment 540
610 REM
620 IF TEST >= PUTT (I) THEN PUTT (I) = TEST
630 IF JJJ >10 THEN GOTO 660
640 PRINT PUTT (I), H, PRICE, I, IX, IY
650 IF JJJ = 1 THEN LPRINT, K, PRICE, PUTT
    (I), H, I, IX, IY
660 SAVEPUT (I) = PUTT (I)
670 IX = IX - 1
680 IY = IY + 1
690 NEXT I
700 REM
710 REM If JJJ >1 calculate all possible option
        prices for the beginning
720 REM of the previous time interval
730 REM If JJJ = 1 the program is completed (the
        option price has been
740 REM calculated for the beginning of the first
        time interval)
750 REM
760 If JJJ >THEN GOTO 390
770 DATA 800.00, 800.00, 0.1280, 75, 0.375, 0.1755
780 END
790 REM
800 REM S = Futures price at the beginning of the
            first time interval
810 REM K = Strike or exercise price
820 REM R = Annualized riskless interest rate
830 REM T = Number of equal time intervals until
            option expiration date
840 REM TAU = Fraction of year until option ex-
              piration date
850 REM SIGMA = Standard deviation of the rate
                of change in the futures
                price for 1 year
860 REM
870 REM PUTT (I) = Put option prices for the cur-
                   rent time interval
880 REM SAVEPUT (I) = Put option prices for the
                      following time interval
890 REM JJJ = Number of possible futures prices
              for current time interval
900 REM IX = Number of futures price increases
             since the beginning of the
             first time interval
910 REM
920 REM IY = Number of futures price decreases
             since the beginning of the
             first time interval
930 REM
940 REM replace statements 320 and 580 with those
        shown below to
950 REM calculate call option prices
960 REM 320 PUTT (I) = PRICE - K
970 REM 580 TEST = PRICE - K
980 REM Delete statement 620 to calculate Euro-
        pean option prices
```

In Earlier Issues

Those of us involved in economic research should care about methodology because it is the floor we walk on. If economics is to claim a scientific stature, then the profession must formally define a program for rejecting or accepting a proposed economic theory and, on the basis of accepted theory, produce accurate and pertinent predictions that, in principle, can be empirically tested.

Roger Conway
Vol. 34, No. 1, January 1982

Dynamic Relationships and Efficiency of Rice Byproduct Prices

By B. Wade Brorsen, Warren R. Grant, and Jean-Paul Chavas*

Abstract

This article analyzes the dynamic relationships among weekly prices of rice byproducts, long grain rice, and corn, using causality tests and dynamic multipliers. The authors use forecasts to evaluate the time series model. Rice byproducts prices may be influenced more by shifts in demand than in supply. Long grain rice prices are related to brewers and seconds prices, but not to bran or mill feed prices. Mill feed and corn prices move together. Corn prices exhibited no consistent relationship with seconds, brewers, or long grain prices.

Keywords

Prices, rice, byproducts, causality, multipliers

Byproducts are marketable items produced as "residues" in the process of making or transforming a particular commodity. As such, the revenue from selling byproducts is usually quite small compared with the revenue obtained from the main commodity. For this reason, the supply of byproducts is generally closely related to the supply of the commodity. In other words, the price of the commodity may be a major shifter in the supply function for its byproducts. On the other end, byproducts may be used in some production processes in competition with other substitute products. Then, the demand for byproducts could be heavily influenced by the price of these substitutes. In a competitive market, the pricing of byproducts may depend on the price of the commodity simultaneously produced and on the price of products competing for their use. If one is investigating price discovery for byproducts, empirical analysis of these price relationships is relevant. In particular, knowledge of how short-term fluctuations in any of these prices influence the other prices, such as the direction, magnitude, and speed of price transmission from one market to another, would be useful.

This article focuses on several major rice milling byproducts: second heads, brewers rice, rice mill feed, and rice bran.[1] Because these byproducts are used for feeding livestock or in breweries, they may be close substitutues for corn. Indeed, corn, second heads, brewers rice, and long grain rice are major inputs in the brewing industry, accounting for 99 percent of the grain used as the adjunct in the brewing process (*30*).[2] Brewers use about two times more corn than rice and rice byproducts. This article analyzes the dynamic relationships among weekly prices of rice byproducts, long grain milled rice, and corn. The knowledge of such dynamic relationships can help rice millers formulate their marketing plans for rice byproducts. More specifically, we investigate the strength of substitutability between rice byproducts and corn. We also explore whether price adjustments have been caused by shifts in supply or shifts in demand. Finally, by examining the speed of price adjustments among markets, we provide some evidence of the efficiency of the markets.

*Brorsen is an assistant professor at Purdue University; Grant is an agricultural economist with the National Economics Division, ERS; and Chavas is an associate professor at the University of Wisconsin. This research was funded by Texas Rice Research Foundation (Econo-Rice Project), Texas Agricultural Experiment Station, and ERS. Technical Article 18801 of the Texas Agricultural Experiment Station.

[1]Rice hulls, the major byproduct in terms of quantity, is of relatively little value. It is sometimes ground and mixed with bran to form rice mill feed and has several other uses. Because it is unimportant economically and no price series exist, rice hulls are not considered in this analysis.

[2]Italicized numbers in parentheses refer to items in the references at this end of the article.

A Theoretical Model

A theoretical discussion of competitive price determination is presented in this section. Our discussion focuses on the hypothesized direction of price transmission effects. We will discuss the price transmission between one byproduct, the main product (long grain rice), and the hypothesized substitute for the byproduct (corn) in the context of a static model, using the following notation: upper case letters represent quantities whereas lower case letters represent the corresponding prices.

Modeling Price Transmission

First, denote aggregate supply function for corn by:

$$C^s = f_1(c, x) \tag{1}$$

where C^s is the quantity of corn supplied, c is the price of corn, and x represents other factors influencing supply (such as rainfall or Government farm programs). The demand for corn should not be greatly influenced by the price of rice or rice byproducts because only a small portion of corn is used where these are substitutes. However, the aggregate derived demand function for corn is defined here in its more general form where:

$$C^d = f_2(c, b, r, y) \tag{2}$$

where C^d is the quantity of corn demanded, b is the price of the rice byproduct, r is the price of long grain rice, and y is other factors. Some of the rice byproducts compete with lower quality long grain rice. Therefore, the aggregate derived demand for long grain rice (R^d) is specified as:

$$R^d = f_3(c, b, r, v) \tag{3}$$

where v is a set of exogenous demand shifters. The supply of milled long grain rice (R^s) would be affected by its own price as well as its byproducts:

$$R^s = f_4(b, r, w) \tag{4}$$

where w is a set of exogenous supply shifters.

The demand for the rice byproduct should be influenced by the prices of its two closest substitutes, corn and long grain rice. Thus, the derived demand for the byproduct (B^d) is:

$$B^d = f_5(c, b, r, z) \tag{5}$$

where z is a set of exogenous demand shifters. The rice byproducts are basically produced in fixed proportions to the production of milled rice. Thus, the supply of rice byproducts (B^s) is specified as:

$$B^s = aR^s \tag{6}$$

where a is a constant of proportionality.

If each market is in equilibrium, then one can complete the system of equations supply and demand in each market ($B^s = B^d$; $R^s = R^d$; $C^s = C^d$). Equations (1) to (6) can then be solved for the market equilibrium prices as reflected by the following reduced-form equations:

$$c = g_1(\theta) \tag{7}$$

$$r = g_2(\theta) \tag{8}$$

$$b = g_3(\theta) \tag{9}$$

where $\theta = (x, y, v, w, z)$. These reduced-form equations simply state that prices are a function of the exogenous supply-demand shifters in equations (1) to (6), x, y, v, w, and z. These equations are the general equilibrium relations which are relevant to analyze the effects of shifts in exogenous variables when a static model is appropriate. However, the static model may not be appropriate if markets are slow to adjust. Among several possible reasons for dynamic price movements is the possibility that market traders may make pricing decisions based on delayed information.

The concept of market efficiency is related to the speed of price adjustments. Fama defined an efficient market as one that fully reflects all available information. If prices adjust instantaneously to exogenous shocks, then the market is efficient and, in the absence of transaction costs, price changes cannot be predicted ahead of time (*5*). When price adjustments are slow, the corresponding markets are then inefficient if price changes can be predicted ahead of time. In this case, the dynamics of price transmission provide information on the degree of market inefficiency.

The tests of efficiency used in this article are random walk type tests where the information set has been expanded to include several prices. Danthine urged caution in interpreting zero autocorrelation in returns tests because they are simultaneous tests of

market efficiency, perfect competition, risk neutrality, constant returns to scale, and the impossibility of corner optima, such as supply shortage or deficient demand (*4*). Frankel maintains the joint hypothesis even extends to include the absence of market "news" (*7*). Another criticism is, as Swamy, Barth, and Tinsley pointed out, that the rational expectations model, of which the efficient markets model is a special case, requires the equivalence of subjective and objective probabilities (*24*).

Prices in competitive markets are expected to fully adjust in the long run. Arbitrage should become more effective over time as more information becomes available and as economic agents have time to adjust their decisions. In this case, competitive prices would tend to converge to an equilbrium after a few periods, implying the dynamic price adjustment is stable. The longrun adjustment is expected to be similar to the adjustment that would take place in a static framework. Thus, the direction of lagged effects should be the same as the original shift in supply or demand.

Motivation of the Time Series Approach

To examine price adjustments, we must introduce dynamics into the static model. Our approach uses time series modeling. The analysis is set in the context of the reduced-form equations (7), (8), and (9) made dynamic:

$$\begin{bmatrix} c_t \\ r_t \\ b_t \end{bmatrix} = h\,[\theta_t, \theta_{t-1} \ldots] \tag{10}$$

where prices respond to the information provided by current and past supply/demand shifters, θ_τ, $\theta_{\tau-1}$, and so forth.

The components of θ involve many factors (such as weather, rumors, sales, and expectations) which are difficult to measure, especially for short time periods such as a week. An alternative approach used here is to assume that these many factors are generated by stochastic processes which can be identified and estimated. In this time series modeling approach, we can alternatively express equation (10) as:

$$\begin{bmatrix} c_t \\ r_t \\ b_t \end{bmatrix} = d + s + e_t \tag{11}$$

As equation (11) shows, the price series decompose into three parts: the deterministic part, d; the short memory portion, s (in this analysis s consists of lagged prices with the deterministic component subtracted), which is assumed to be covariance stationary; and the error term, e_t, which is a zero mean white noise process. The deterministic part, d, involves trend and seasonality factors which cause the mean of the price series to be a function of time. These factors reveal nothing new about the market's response to information. Because time series analysis methods assume that the mean is not a function of time and because we are interested in studying the market's use of information, the deterministic component, d, must be removed (filtered). The stochastic process, $s + e_t$, reflects how new information is processed by the markets. If s is zero, then price adjustments are instantaneous, suggesting the markets are efficient, at least in a "weak form" sense (*5*).[3] The process $s + e_t$, is modeled by use of autoregressive models (*1*). The white noise process, e_t, reflects the price variations which are not predictable ahead of time.

Data and Modeling Approach

This section presents the modeling approach used to investigate the dynamics of prices of four major rice byproducts: second heads, brewers rice, bran, and mill feed. We investigated corn prices because corn is a major substitute for the byproducts. We also investigated the relationships between the price of long grain rice and the prices of its byproducts. Our analysis relies on both univariate and multivariate time series modeling.

The data are weekly prices for October 1976 to September 1981 obtained from USDA publications: *Rice Market News*, *Rice Outlook and Situation Report*, and *Grain Market News* (*27, 28, 29*). The data include prices for rice byproducts in Texas, No. 2 yellow corn in Kansas City, and No. 2 long grain milled rice in Texas.

[3]Fama distinguishes among different information sets in his definition of efficiency. The information set for this weak form test of efficiency consists of past prices only.

Trend and seasonality are deterministic components that reveal nothing new about the market's response to new information. Therefore, they must be filtered before applying time series analysis and testing the efficiency of information for shortrun analysis because they avoid the need to specify the longrun behavior of the process (*6*). Since this study attempts to model shortrun market fluctuations, trend components are removed by first differencing. Regressions against a linear time trend indicated no significant linear trend remained in the first differenced data. Seasonality components are removed by use of a spline function (*16*).[4] Spline functions were chosen in the absence of prior knowledge of the precise functional form because they provide a flexible method of approximating an unknown function with a minimum number of parameters. Examination of the periodogram of the filtered data indicated that the procedure removed seasonality.

The filtering process is designed to remove effects of transaction costs. The first-difference filter should negate the effect of time trends and transaction costs between locations and between levels of the marketing channel. The seasonal adjustment should remove the effects of storage costs.

Causality Tests

Time series models can give insight as to whether or not a market is efficient by examining causality and feedback relationships. Granger defined causality in terms of predictability: a variable X does not cause another variable Y, with respect to a given set of information that includes both X and Y, if Y cannot be predicted more accurately by use of past values of X than if the information about X is not used (*9*). If X does not cause Y, but Y causes X, the causality is unidirectional. If the causality is bidirectional (X causes Y and Y causes X), it is called a feedback relationship. The causality tests suffer from a number of theoretical problems (*3*). We follow Mishkin's caveat that "...the issue here is the predictive content of the information—which is what Granger causality is really meant to analyze—and does not involve the tricky concept of economic causality which has led to so much confusion in the literature" (*19*). Thus, "causality" tests are employed in this article as tests of relative predictive efficiencies.[5]

Fama's market efficiency tests, developed for security markets, can be used for commodity markets if the data transformations remove the effects of storage, transportation, and other transaction costs (*5*). Assuming these transformations are sufficient, if a model cannot be found that helps predict the future using only filtered data, the market is efficient in the weak form sense. For a univariate time series, the sufficient condition for an efficient market would be that the price series is an AR(O). This means that, except for seasonal adjustments, prices of the corresponding markets follow a random walk with drift.

Significance tests for the cross correlations and regression of Y on past X alone are biased if the series are highly correlated (*10*). To overcome the problems associated with analyzing two highly correlated series, a proposed method consists of fitting univariate time series models to the data and analyzing the cross correlations of the residuals (*11, 14*). One drawback of this approach, as Schwert demonstrated, is that this filtering procedure may not preserve causal relationships (*21*). Also, no inference on instantaneous causality can be made from examination of the cross correlations of the residuals (*18, 20*).

Following this approach, we selected the orders of the univariate models using Akaike's Information Criterion (AIC) (*1*).[6] The AIC is a weighting function between parsimony and accuracy. We estimated the parameters of the univariate models by the least square method. These estimates and their standard errors are consistent and asymptotically efficient if the residuals are uncorrelated and the true order is selected. However, Shibata demonstrated the AIC may overestimate the true order (*22*). Thus, our estimates will be consistent, in general, only if selection of the order of the model is not considered part of

[4]The spline function involves estimating different polynomials in time over different sections of the data and then placing restrictions on the functions to make them continuous and differentiable. In this case, we estimated four cubic polynomials in time, one for each calendar quarter. The switching points approximately coincide with quarterly stock reports.

[5]As Conway and his colleagues point out, this predictive efficiency is valid only in the linear least squares sense; nothing can be said about nonlinear prediction from these tests. (*3*).

[6]Theoretical work has pointed out some potential problems with the AIC. Under certain conditions, the AIC can be undefined or may not have well defined maximum solutions (*22*).

the estimation procedure.[7] We performed tests for causal direction and contemporaneous correlation. The test statistics have chi-square distributions under the null hypotheses of no relationship.

Multivariate time series methods allow for more than a comparison of pairs. Sims argued causality tests using multivariate methods may be the most natural way of performing causality tests, but he rejected them because of lack of uniqueness of the joint autoregressive moving average (ARMA) process (*23*). One can avoid this difficulty by adhering strictly to a pure autoregressive (AR) model (*15*).

To further investigate multimarket price series relationships, we also modeled the price series by multivariate time series analysis, again in the context of an AR model. We selected the order of the multivariate AR model using an AIC and estimated the multivariate model by seemingly unrelated regression. The test of causality in the context of a multivariate AR model involves testing the restriction that all lagged values of a particular variable are zero (*26*). For example, if the null hypothesis is that Z does not cause Y directly, we would test the restriction that the coefficients Z through Z_{t-2} are zero in the Y equation where p is the order of the AR model. To check the adequacy of the AR model, we performed tests for white noise of the residuals using both Fisher's Kappa statistic and Bartlett's Kolmogorov-Smirnov statistic (*8*).

Multipliers

The causality tests previously mentioned provide no information about the dynamic properties of the model—that is, how the impact of price changes are transmitted through the markets. They do not show the net impact of one market on another. In a multimarket framework, a price change in one market has both a direct impact and an indirect impact on other markets. Causality tests do not provide much information about efficiency in the presence of a feedback relationship. Dynamic multipliers are useful for discussing efficiency because they incorporate both the direct and indirect impacts. Thus, we further examined the dynamic properties of the underlying series by calculating dynamic multipliers for the multivariate autoregressive model.

We did not use the traditional interpretation of dynamic multipliers in this analysis. Typically, dynamic multipliers measure the change in the endogenous variable associated with a one-unit change in the exogenous variable (*2*). Because all predetermined variables are lagged endogenous variables, we calculated dynamic multipliers in this analysis assuming a one-time shock occurs through the error term. Thus, this shock is not specified as to its origin, but rather it represents past shocks. The dynamic multiplier analysis involves the calculation of three different multipliers. The mth delayed-run multiplier (DRM(m)) shows the impact of a one-time shock in time period $t - m$ on price changes in time period t. The mth intermediate-run mulitplier (IRM(m)) measures the total impact of a one-time shock to the system on the expected price level m periods ahead. The intermediate-run multiplier is the cumulative of the price changes which is the sum of the delayed-run multipliers. The longrun multiplier (LRM) is the impact on the expected price when a new equilbrium is reached. The longrun multiplier is the same as the intermediate-run multiplier as m approaches infinity (*2*).

In this analysis, the one-time shock occurs through the error terms in the autoregressive model for the deseasonalized price change. This shock results in both an immediate change in current price (P_t) and in a change in the expected value of future price changes. The DRM measures the change in the expected value of future price changes because it measures changes in the future values of the dependent-variable, deseasonalized price changes. Thus:

$$\mathrm{DRM}(m)_{ij} = \frac{dE[\Delta P_i(t+m)]}{dP_j(t)} \qquad (12)$$

The total change in $E(P(t+m))$, the expected value of price, m time periods in the future, resulting from a shock in time t is the change in expected future price changes which is the intermediate-run multiplier. The intermediate- and longrun multipliers measure the change in the expected value of

[7]If the selection of the order of the model is considered part of the estimation process, an inconsistent estimate of the order of the model would affect the sampling estimates and these estimates would also be inconsistent. Hannon's procedure would yield consistent and asymptotically efficient estimates. However, Hannon's procedure is more likely to underestimate the order in small samples, thus producing more biased estimates in small samples (*12*, *13*).

$P_i(t+m)$ associated with a one-unit change in $P_j(t)$ which can be written as:

$$\mathrm{IRM}(m)_{ij} = \frac{dE[P_i(t+m)]}{dP_j(t)} \tag{13}$$

$$= \sum_{k=1}^{m} \frac{dE[\Delta P_i(t+k)]}{dP_j(t)}$$

$$= \sum_{k=1}^{m} \mathrm{DRM}(k)_{ij}$$

where E is the expectation operator and $\mathrm{IRM}(m)_{ij}$ is the mth intermediate-run multiplier measuring the impact of P_j on P_i. The longrun multiplier is the limit of IRM as m approaches infinity.

Because the IRM is simply the sum of the DRM, a measurement of the amount of time it takes the market to adjust to shocks is the highest value of m for which the delayed-run multiplier is significant. Calculating this measurement of the adjustment period proves useful to discussing the speed of price adjustments.

Prediction

One way to validate a model is to evaluate how well it predicts the aspects of the real world that it was designed to model. We made and evaluated out-of-sample forecasts for the multivariate AR models as a means of validation. The predictive ability of the model also gives some insight into the degree of inefficiency. The real test of efficiency is whether or not the model can be used to predict the future with some degree of reliability and thus to develop profitable trading rules. Out-of-sample forecasts will provide additional evidence to show if the model could have been used by a trader to make profits in the forecast period.

We calculated forecasts for 13 weeks (October 1981 to December 1981). This relatively small sample implies that the forecast accuracy results should be interpreted with caution. The forecasts can be computed as:

$$P(t+h|t) = P(t+h-1|t) + \widetilde{C}(t+h|t) + \Delta P(t+h|t) \tag{14}$$

where $P(t+h|t)$ is the predicted price in time, $t+h$, given the information available in t; $P(t)$ is the actual price in time, t; $\widetilde{C}_{t+h}$ is the predicted seasonal price change in $t+h$ (predicted value of the spline function); $\Delta P(t+h|t)$ is the predicted deseasonalized price change (predicted value of the autoregressive model using deseasonalized price changes); and h is the number of steps ahead that the forecast is made. This is dynamic simulation. A static simulation is a series of one-step-ahead forecasts. We used both static and dynamic forecasts. A static model should perform better because it uses more information (*17*).

We evaluated the forecasts using Theil's U2 statistic (*25*). The statistic compares the root mean squared errors from the time series forecasts with those obtained from a no-change model, that is, a random walk model. In the absence of transaction cost, a market that follows a random walk is efficient. Therefore, if the time series model cannot predict better than a random walk model, the market is considered efficient. The U2 statistic is:

$$\mathrm{U2} = \frac{\sqrt{\sum_{t=1}^{T} (\mathrm{Predicted}_t - \mathrm{Actual}_t)^2}}{\sqrt{\sum_{t=1}^{T} (\mathrm{Actual}_t)^2}} \tag{15}$$

where $\mathrm{Predicted}_t$ and Actual_t are a pair of predicted and observed changes from the previous actual level. The U2 inequality coefficient ranges from zero to infinity. If the predictions are perfect, then the predicted value equals the actual and U2 equals zero. A no-change forecast model where the predicted value equals last period's price gives a U2 value of 1. Any value of U2 greater than 1 means the model is worse than a no-change forecast model.

In addition to the 13 static and dynamic forecasts, a series of eight 6-week-ahead forecasts are made. These forecasts are equivalent to the last predicted value of a six-period dynamic simulation. In calculating U2 statistics for these forecasts, we compared the 6-week-ahead forecasts with the actual values at the beginning of the dynamic simulations.

Results

We used first differencing and spline functions to remove deterministic components and performed the

analysis using the filtered data. Using cross correlations of residuals from univariate models, we initially performed causality tests among alternative price series. We then analyzed the dynamics of price relationships using multivariate modeling. Dynamic multipliers provide useful information to investigate the economic implications of the models. Next, we used forecasts of the prices to evaluate the ability of the time series model to describe and predict the actual behavior of the market.

Univariate Results

We selected univariate AR models using the AIC and estimated the models by ordinary least squares procedures. None of the models selected is an AR(0) (table 1). Given Fama's definition of market efficiency (in the weak form sense), all markets are inefficient in processing the information reflected in their own prices. Long grain rice and corn prices have the shortest AR models with an AR(1). Second heads and mill feed both have an AR(5) which is the longest order. Thus, the primary products are the quickest to adjust whereas the prices of the less important byproducts adjust more slowly.

Comparing cross correlations of the univariate AR residuals reveals that bran and mill feed prices, by far, have the strongest relationship to the current period with a chi-square statistic three times that of any other byproduct price (table 2). Other prices with a contemporaneous relationship significant at the 5-percent level are seconds and bran, seconds and long grain, brewers and long grain, and mill feed and corn.

Comparing cross correlations involving 10 lags contains only two "causality" results significant at the 5-percent level (table 2). Long grain prices lead brewers prices, and corn prices lead long grain prices. Only bran and mill feed have a strong relationship.

The causality results using either 5 or 20 lags are different (table 3). Together these have five "causality" results that are significant at the 5-percent level. Both results also show long grain prices cause brewers prices. However, none of the other causality results is consistent, suggesting that these results may be spurious. Seconds prices and bran prices are not caused by any of the other prices regardless of the choice of length of lag.

Table 1—Univariate autoregressive models[1]

Series	Intercept	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	AIC order	R-squared
Long grain	– 0.5430 (– .13)[1]	– 0.1524 (– 2.45)[2]						1	0.023
Seconds	– .0819 (– .03)	– .0440 (– .70)	– 0.0112 (– .18)	– 0.0995 (– 1.61)	– 0.0859 (1.38)	– 0.1726 (– 2.73)[2]		5	.055
Brewers	.3396 (.25)	– .0077 (– .12)	– .0454 (– .73)	– .0659 (– 1.05)	.1569 (.250)[2]			4	.032
Bran	– .1662 (– .16)	.2860 (4.62)[2]	.0469 (.73)	– .1984 (– 3.21)[2]				3	.117
Mill feed	– .0734 (– .11)	.2612 (.414)[2]	.0220 (.34)	.2077 (3.25)[2]	– .2100 (– 3.23)[2]	– .0981 (– 1.53)		5	.149
Corn	– .1595 (– .24)	.2561 (4.24)[2]						1	.066

Blanks indicate not applicable.
[1]t-values are in parentheses.
[2]Significant at the 5-percent level.

Table 2—Bivariate causality results for rice byproduct prices, using 10 lags[1]

Commodity		Null hypothesis		
Y1	Y2	Y1 ≠> Y2	Y2 ≠> Y1	No contemporaneous correlation
Seconds	Brewers	2.2	6.4	0.01
Seconds	Bran	12.2	5.2	4.10[2]
Seconds	Long grain	8.3	11.6	12.10[2]
Seconds	Mill feed	5.1	11.9	.20
Seconds	Corn	18.2	9.1	2.40
Brewers	Long grain	16.2	24.2[2]	4.20[2]
Brewers	Mill feed	4.9	11.6	.03
Brewers	Corn	4.8	13.3	.92
Bran	Mill feed	16.2	19.5	36.60[2]
Bran	Corn	10.5	14.1	1.2
Long grain	Mill feed	5.3	10.6	.003
Long grain	Corn	5.2	20.2[2]	.40
Mill feed	Corn	6.9	15.6	4.50[2]

[1]The test statistic is calculated including 10 lags and is distributed chi-square with 10, 10, and 1 degrees of freedom for each respective test. Thus, the critical values at the 5-percent level are 18.3, 18.3, and 3.84, respectively.
[2]Significant at the 5-percent level.

Table 3—Bivariate causality relationships for rice byproduct prices, using 5 and 20 lags[1]

Commodity		Null hypothesis			
		5 lags		20 lags	
Y1	Y2	Y1 ≠> Y2	Y2 ≠> Y1	Y1 ≠> Y2	Y2 ≠> Y1
Seconds	Brewers	1.7	4.4	28.8	9.2
Seconds	Bran	4.4	2.3	19.5	10.2
Seconds	Long grain	6.9	9.8	26.1	22.8
Seconds	Mill feed	2.6	.93	24.7	20.1
Seconds	Corn	5.4	5.4	33.3[2]	22.7
Brewers	Bran	7.4	2.6	25.9	17.2
Brewers	Long grain	12.1[2]	20.7[2]	22.7	44.9[2]
Brewers	Mill feed	3.4	3.8	14.2	22.8
Brewers	Corn	1.4	3.1	9.3	33.1
Bran	Long grain	7.7	3.0	26.6	14.9
Bran	Mill feed	12.6[2]	9.6	26.8	24.5
Bran	Corn	4.5	10.3	20.6	18.5
Long grain	Mill feed	.8	7.8	11.4	18.2
Long grain	Corn	3.4	7.0	16.3	29.5
Mill feed	Corn	6.0	8.3	16.9	20.2

[1]The test statistic is a distributed chi-square with m degrees of freedom. Thus, the critical values at the 5-percent level are 11.1 and 31.4, respectively.
[2]Significant at the 5-percent level.

Multivariate Results

We selected an AR(1) from the AIC criterion for the multivariate model (table 4). The multivariate R-squared values are lower than the univariate R-squared values for seconds, brewers rice, and mill feed. These three price series have univariate AR orders of 4 or 5, and we did not include these lags in the multivariate model. Multivariate causality results can be determined if one examines the significance of individual coefficients (table 4). The multivariate causality results show that long grain prices cause second prices, corn prices cause bran prices, and bran and mill feed prices have a feedback relationship. Thus, long grain prices, corn prices, and brewers prices are not led by any other prices and appear to be efficient in processing information from the other markets. The null hypothesis of white noise residuals is not rejected for any of the price series when both Fisher's Kappa statistic and Bartlett's Kolmogorov-Smirnov statistic are used (*8*).

The measurement of the adjustment period shows all prices adjust very quickly, with the longest impact taking 2 weeks (table 5). The own-price longrun multiplier of the long grain prices is significantly less than 1, indicating that any price changes are later modified. This change could result if the Texas long grain price overreacted to new information. The own-price multiplier for bran, mill feed, and corn prices are significantly greater than 1, indicating these markets respond gradually (1-2 weeks) to new information.

Corn has a large impact on the other markets, ranging from 0.22 for mill feed to 0.42 for bran; however, only the impact on bran is significant at the 5-percent level. The impact of corn is large because the means and standard deviations of the other prices are larger than those for corn.

All prices are measured in cents per hundredweight, but 100 pounds of corn is worth less than 100 pounds of the other commodities. Long grain prices have a small, but significant, impact on prices of second heads (0.08). Mill feed and bran both affect each other, with mill feed having the larger impact (0.39 vs 0.18).

Table 4—Multivariate autoregressive model for rice byproducts[1]

Independent variable	Dependent variable[1]					
	Long grain_t	Seconds_t	Brewers_t	Bran_t	Mill feed_t	Corn_t
Intercept	0.09405 (.02)	0.4500 (.17)	0.4374 (.33)	−0.0028 (−.00)	−0.0316 (−.05)	0.0148 (.02)
Long grain_{t-1}	−.1598 (−2.52)[2]	.1007 (2.43)[2]	−.0222 (−1.05)	.0185 (1.17)	.0024 (.22)	.0050 (−.49)
Seconds_{t-1}	.0735 (.76)	−.0908 (−1.43)	.0563 (1.74)	−.0444 (−1.84)	.0048 (.29)	−.0020 (−.13)
Brewers_{t-1}	−.0765 (−.40)	−.0391 (−.32)	−.0208 (−.33)	.0153 (.32)	−.0202 (−.62)	−.0161 (−.53)
Bran_{t-1}	−.4324 (−1.62)	−.1511 (−.87)	−.1144 (−1.29)	.2045 (3.09)[2]	.1113 (2.44)[2]	.0006 (.01)
Mill feed_{t-1}	−.0298 (−.08)	.2497 (.97)	.0763 (.58)	.2776 (2.83)[2]	.1738 (2.57)[2]	−.0711 (1.12)
Corn_{t-1}	.4242 (1.11)	.2493 (1.00)	.2276 (1.79)	.2017 (2.12)[2]	.1042 (1.59)	.2824 (4.59)[2]
R-squared	.040	.037	.028	.150	.104	.080

[1]t-values are in parentheses.
[2]Significant at the 5-percent level.

Table 5—Longrun multipliers for rice byproduct prices

Impact[1]	Multipler	t-value	Prob > |t|	Adjustment period[2]
BW - > BW	0.972	- 0.46	0.64235	0
TX - > BW	- .017	- .97	.33466	0
SC - > BW	.054	1.79	.07521	0
BN - > BW	- .135	- 1.26	.20710	0
MF - > BW	.037	.34	.80779	0
CN - > BW	.284	1.68	.09352	0
BW - > TX	- .076	- .47	.63872	0
TX - > TX	.860	- 2.98	.00320[3]	1
SC - > TX	.083	.91	.36438	0
BN - > TX	- .500	- 1.77	.07839	0
MF - > TX	- .213	- .53	.59437	0
CN - > TX	.34	.76	.44943	0
BW - > SC	- .053	- .46	.64582	0
TX - > SC	.077	2.32	.02135[3]	1
SC - > SC	.927	- 1.28	.20109	0
BN - > SC	- .185	- .92	.35915	0
MF - > SC	.182	.64	.52197	0
CN - > SC	.326	1.03	.30605	0
BW - > BN	.006	.09	.92842	0
TX - > BN	.015	.77	.43906	0
SC - > BN	- .051	- 1.51	.13258	0
BN - > BN	1.312	2.61	.00953[3]	2
MF - > BN	.390	2.30	.02196[3]	1
CN - > BN	.419	2.22	.02731[3]	2
BW - > MF	- .026	- .58	.56200	0
TX - > MF	.005	.36	.72074	0
SC - > MF	- .003	- .14	.88880	0
BN - > MF	.176	2.26	.02457[3]	2
MF - > MF	1.247	2.24	.02598[3]	1
CN - > MF	.224	1.82	.06972	0
BW - > CN	- .019	- .46	.64296	0
TX - > CN	- .006	- .54	.58816	0
SC - > CN	- .004	- .21	.83768	0
BN - > CN	- .009	- .13	.89395	0
MF - > CN	- .123	- 1.24	.21471	0
CN - > CN	1.362	3.28	.00118[3]	1

[1]BW = brewers, TX = long grain, SC = seconds, BN = bran, MF = mill feed, CN = corn.
[2]The adjustment period is the time the delayed-run multiplier takes to become insignificant at the 5-percent significance level.
[3]Significantly different from 1 (0) for the own-(cross-) price multiplier at the 5-percent level.

The only U2 value less than 1 for the static simulations of the multivariate model is for mill feed, whereas corn has the largest U2 value at 3.45 (table 6). The multivariate AR model does not predict as well as a random walk model which implies that the market is efficient as the model could not be used to make an "above-normal" profit. The six-step-ahead U2 values are similar to those for the static forecasts. As expected, the dynamic forecasts are poor, with U2 values ranging from 1.68 for mill feed to 7.47 for brewers. These predictions are for a relatively small sample (13 observations), but they imply that inefficiency is low, if it exists.

Conclusions

We used univariate and multivariate time series modeling to investigate rice byproduct pricing. Most of the relationships between the price series investigated are weak. Most prices are not even related in the current period, implying these commodities do not compete with each other. Mill feed and corn prices move together, implying that there may be some substitution between these commodities. Corn prices have no consistent relationship (current or lagged) with seconds, brewers rice, or long grain prices, implying corn and these commod-

Table 6—Predictive performance of the multivariate autoregressive model for rice byproduct prices using Theil's U2 statistic[1]

Price series	Static forecasts[2]	Dynamic forecasts[2]	Six-step-ahead forecasts[3]
Long grain	2.03	6.51	2.16
Seconds	1.42	6.12	1.50
Brewers	2.94	7.47	1.93
Bran	1.05	3.69	.94
Mill feed	.95	1.68	.94
Corn	3.45	6.01	6.24

[1]A no-change model has a U2 value of 1.0 (*25*).
[2]Calculated using 13 out-of-sample forecasts.
[3]Calculated using 8 out-of-sample forecasts.

ities do not exhibit close substitutability. There may be some substitution between long grain and either seconds or brewers rice. Long grain rice prices are related to brewers and seconds prices, but not to bran or mill feed prices. Because the prices of long grain rice and the four byproducts are not all related, shifts in the supply of rough rice were probably less important in pricing rice byproducts during the observation period. In other words, the results suggest that rice byproduct prices may be more influenced by shifts in their demand than shifts in their supply. Further research analyzing these should, therefore, try to focus on the determinants of the derived demand for rice byproducts.

All price series analyzed here are inefficient in processing information reflected in their own prices according to the univariate results. However, most of the prices are fairly efficient with respect to the information reflected by the other prices. The low R-squared values, short adjustment periods, and poor forecasts all indicate that the degree of inefficiency in these markets may be low.

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In Earlier Issues

In view of current concerns over Government regulation and of the debates on new food and agricultural policy direction and legislation, dairy policy merits careful consideration. Some important questions that need to be answered are: How much instability can be expected as a result of program removal? Is this expected level of instability tolerable? Who might suffer as a result of this level of instability, and by how much? Who might benefit from removal of the dairy programs, and in what way?

M. C. Hallberg
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Research Review

Agricultural Options and Price Supports: Competitive or Compatible?

By Lyle P. Schertz*

The initiation of option trading raises important questions about the potential relationships between options for domestic agricultural commodities and Government price supports. These considerations logically fall into three categories: (1) contrasts and similarities between options and price supports, (2) conditions in which options and price supports could be competitive with each other, and (3) ways in which options might be used to transfer price risks from producers to the public.

Contrasts and Similarities

The roles of options differ from the roles of price-support programs. Option markets essentially deal with risks of changes in price within a marketing year. Option markets will not generate market prices different from those warranted by supply and demand conditions. Furthermore, they will transfer price risks only at a premium.

In practice, exchanges are expected to initiate trading of options with strike prices that approximate the then-current supply and demand conditions. As commodity prices change in response to changes in these supply and demand conditions, exchanges are expected to trade options with correspondingly different strike prices.

Government activity, natural phenomena, and actions of entrepreneurs will influence the probability distributions of prices, the alternatives available to producers and uses of farm products and, therefore, the combination of exercise prices and premiums in the option markets. Thus, the strike prices and related premiums of option contracts could reflect a variety of institutional arrangements. But, prices and premiums would vary with differing institutional environments. For example, if the Government were facilitating the withholding of 50 million acres from production to protect a corn price support of $3.00, prices and premiums would differ from a situation in which there was no acreage diversion and the support price was $1.75.

Price-support programs also involve transfers of price risks. They involve put-type arrangements in that nonrecourse loans permit producers to avail themselves of the better of market prices or support prices. An initial choice to use price-support loans does not preclude repaying the loans if market prices become attractive. The public, through a Government agency, accepts the risk of market-clearing prices which are below price-support levels. This arrangement contrasts with option markets where market participants carry the price risks.

Options and price supports differ in two ways that are particularly relevant to discussions about whether they are competitive or compatible. First, price supports cost the producers nothing or represent a "minimal cost," such as diverting acreage from production. In contrast, options will not be free. Theory and observations of option markets such as the sugar options on the Coffee, Sugar and Cocoa Exchange and the initial trading in soybeans options on the Chicago Board of Trade suggest that the premiums will be substantial, especially compared with the nominal or zero cost to producers of the put feature of price-support loans.

Second, price-support levels have frequently been set to raise prices above longrun, market-clearing levels, thereby transferring income to farmers. To maintain these higher prices, the Government has taken steps (1) to isolate stocks of the commodity from the market, (2) to restrain the use of resources such as by diversion of land to other uses, and (3) to expand product demand to protect the levels of price support. Dependence on price supports to effect income transfers has been reduced in recent years.

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Producers have been subsidized with direct payments geared to the difference between target prices and market prices. Thus, there is less pressure to use price supports to transfer income. The accumulation of Government-controlled stocks in the inventories of the Commodity Credit Corporation (CCC) and in farmer-owned reserves indicates, however, that price supports continue to involve income transfers from society to producers.

Both options and price supports involve transfers of price risks. Options will have strike prices that approximate market conditions. Price supports, in fact, are often designed to change conditions. In doing so, they have caused income transfers and will probably do so in the future. The availability of price supports without cost to users in contrast to premiums for options and the dependence on price support for income transfers are critical differences between options and price supports.

Competitive Conditions

Price supports may be competitive, particularly with regard to their effect on the level and variability of market prices. The volume of trading on option markets will be closely related to price variability of corresponding futures markets. The greater the variability of prices and the greater the risk in production and merchandising, the greater will be the interest by producers and trade firms, such as grain merchants, in seeking price risk protection. Commodity programs which substantially limit price changes would thus limit the interest of potential buyers of calls and puts, including producers, in dealing in options. These same conditions would discourage interest in option trading by trade entities and speculators. Thus, price supports and related program activities such as release of Government stocks that substantially dampen price changes will adversely affect the volume of options trading.

Price supports are part of a set of Government programs that includes target prices, deficiency payments, acreage diversion, storage arrangements, and export subsidies. Policy decisions about specific features of these programs affect commodity supplies and demands and, therefore, the price of futures to which the options relate. The manner in which these decisions are made, as well as the specific resulting decisions, can have important effects on the willingness of speculators to participate in options. Even if Government programs do not substantially limit price variability, erratic decisionmaking by program officials could stifle options trading. For example, decisions to release or accumulate Government-controlled stocks can affect market demands and supplies and, therefore, prices. Such decisions can discourage trading by speculators if the criteria for the decisions are not publicly known before the decisions are announced.

Speculators are particularly wary of markets in which prices can be and are significantly influenced by official administrative and political decisions that cannot be anticipated.

Society's interest in price supports and related programs concerns transferring income to producers and enhancing stability of market prices and economic conditions. Price supports are an important means for Government officials to stimulate production adjustments, stock accumulation, and release and, thus, to enhance price stability over time.

The availability of the "put," implicit to price supports, is one of the reasons some producers participate in Government commodity programs. We do not know the extent to which producers will participate in option markets either directly or through trade options, nor do we know if such participation would mean that they would not participate in price-support-related programs, such as acreage diversion and deficiency payments. Some of the larger, more efficient producers who are now only marginally attracted to Government programs may use the options for transferring price risks and discontinue participation in Government programs. To the extent that they do, the ability of the Government to enhance price stability over time and to influence sector income will be eroded. Such action by producers would be important only if a significant number of them considered the "cost" of complying with program provisions, such as acreage limits, more burdensome than the costs of options.

On the one hand, price-support levels and the manner of deciding about price supports and related programs could stifle the interest of producers, traders, and speculators in options. On the other hand, well-functioning options markets could erode the attractiveness to producers of Government price-support

programs and make it more difficult for the Government to influence market prices and farm income over time.

Possible Merger of Price Supports and Options

The availability of options markets should not cause commodity prices and, therefore, related farm income to differ significantly from prices and farm income levels prevailing without such a market. Options would not substitute for programs that restrain production or expand demand. However, this proposition leaves open the question: Is there some way Government could use option markets to transfer price risks from producers?

One possible approach would be to have Government accept bids from speculators to write put contracts at exercise prices consistent with previous price-support levels. Ownership of these put contracts would, in turn, be distributed to producers who qualify according to specified criteria. This practice could continue as a substitute for the present price-support program.

Alternatively, the Government could provide a specified subsidy to each producer who purchased put options. The subsidy could be less than, equal to, or greater than the premiums paid. Furthermore, the subsidy could be increased or decreased over time, compensating producers for price risk and subsidizing incomes.

These types of arrangements probably would not be as attractive to producers as are the current price-support programs. However, the attractiveness of these arrangements would be geared to the amount of the subsidy. Moving price-support mechanisms to the private sector by using options would obviously erode the ability of the Government to accumulate stocks and, in turn, to mitigate price variability. At the same time, using options markets could be combined with a purchase program targeted at "optimum" stock levels rather than have Government stocks be the byproduct of other activities.

The availability of option markets and a possible merger of price supports with them would highlight the economic value to producers of the transfer of price risk from producers to society with the use of price supports. The value of this transfer has often been ignored.

Summary

Although options and price supports both involve transfers of price risks, they differ in two important ways. First, purchasers of options will incur a cost, a premium; price supports have been free. Second, options will not noticeably affect market prices, and their strike prices will approximate market conditions. Price supports are designed to prevent prices from falling as far as they otherwise might and thereby involve income transfers to producers.

Options have a cost for a purchaser, and price supports are free. Competition between options and price supports could occur in two additional ways. Substantial dampening of price variability with a combination of price supports and management of Government stocks would adversely affect the volume of options trading. Also, erratic decision-making in implementing Government programs such as price supports could stifle options trading by discouraging speculators from participating in the markets.

Well-functioning options markets could also erode some of the attractiveness to producers of Government price-support programs; Government officials would have more difficulty influencing market prices over time. The Government could use options to transfer price risks from producers to the public. Two possible approaches are as follows:

- Use bids from speculators to write put contracts at specified strike prices and distribute the contracts to producers.
- Subsidize producers who purchase put options.

Producers would find neither approach as attractive as the current price-support programs.

Risk Management in Agriculture

Reviewed by David Trechter*

Peter Barry (editor). Ames: Iowa State University Press, 1984, 282 pp., $35.95.

This accessible discussion of how agricultural economists treat risk in theoretical and empirical models fulfills Barry's stated purpose of "[providing] a comprehensive coverage of concepts, methods of analysis, and practical applications involving risk analysis in agriculture." The book is aimed at people who've had limited exposure to economic models incorporating risk concepts. Little mathematical sophistication is assumed or required to understand the material presented.

In addition to the book's accessibility, the general organization of material and the bibliography are praiseworthy. The book is organized into four parts: microeconomic foundations of risk models, farm management applications of these models, financial aspects of risk management, and the application of risk models to aggregate phenomena. Organization of the material into these broad subject areas should increase the book's usefulness, particularly for those wanting to examine a specific topic in more depth, since the authors include many references.

Given the audience for which this book is intended, the discussion is an appropriate mix of theoretical issues and empirical applications. Though not successful in all cases, the general approach is to introduce a topic area, discuss some of the conceptual issues, and describe and critique empirical investigations of the topic.

The book does have some shortcomings. As with most compendiums, the links between the various parts of the book are sometimes obscure. It is not always obvious how a chapter builds on earlier ones. This is particularly true in the first section of the book. Another general problem of edited readings, shared by this book, is repetition. Again, the first section of the book is more prone to this problem than the others. For example, risk models employing safety-first rules are described and discussed in chapters 2, 3, and 5. Additional information is added in each case but the topic could have been adequately and completely treated in one part of one chapter.

Although the microeconomic foundations of risk models are better developed than are the corresponding macroeconomic foundations, the book's first section shows that even in microeconomic risk theory there are areas of disagreement. For example, the utility functions of decisionmakers in risky environments are described by economists in a variety of ways. Examples of different approaches examined in the first section of the book include the Expected Utility Hypothesis, Lexicographic Utility Functions such as Safety First models, and Mean-Variance models (and closely related approaches).

Another controversy discussed in the opening section is the appropriate density function to use in modeling behavior. Most in the field agree that the subjective probability beliefs held by a decisionmaker will be more successful in predicting behavior. However, it is also generally recognized that eliciting these beliefs is difficult, expensive, and susceptible to biases. Furthermore, the magnitude and likelihood of errors increase when one tries to estimate more complex relationships such as the covariance between the income-generating potential of several crops.

The first section also discusses different methods for reducing the size of the choice set confronting a decisionmaker (for example, various stochastic dominance criteria) and the very different approach to studying human behavior in risky situations used by psychologists.

The second section of the book examines the use of risk models in farm management. The most commonly used techniques for implementing these models in the farm management context include quadratic programming (QP), minimization of total absolute deviations (MOTAD, a linear alternative to QP), simulation (using econometric or systems science techniques), and decision trees with payoff matrices. The results of several empirical investigations are presented in this section.

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The book's third section describes the financial aspects of agricultural risk. The treatment of this topic is broken into three parts, one for borrowers, one for lenders, and one on the general impact of inflation on the financial risks associated with agriculture. The treatment of the three is uneven because much less work has been done on risk models of lender behavior. The section develops the distinction between business and financial risk, describes borrower and lender responses to financial risk (such as credit reserves and various amortization plans), and discusses ways inflation affects the financial risk of borrowers.

The final section is the shortest and, in many ways, the most provocative. The application of risk models to macroeconomic phenomena such as international trade or agricultural policy is relatively new. The theoretical underpinnings in this area are still in flux, making empirical work uncertain. For example, farmers' response to agricultural policy changes can be modeled in a rational expectations or an adaptive expections framework. How this response is modeled can have important consequences for the outcome of the analysis. At the very least, the time period in which the uncertainty facing a farmer increases differs in the two approaches.

This final section presents arguments supporting an agricultural policy with automatic adjustment mechanisms. For example, it suggests that Commodity Credit Corporation loan rates be tied to reserve stock levels. If reserve stocks go up by a preestablished percentage, the loan rate would decline by a given amount. The information built into these automatic adjustments would reduce the policy risk faced by farmers and could be incorporated into their planning horizon thereby improving the economic decisions they make.

Risk Management in Agriculture is a good primer for someone interested in how economists model uncertainty in the agricultural environment. Its principal role may be as a starting point for those investigating a specific topic or method. The nonrigorous treatment and extensive bibliography are well suited for this endeavor.

Suggestions for Submitting Manuscripts for *Agricultural Economics Research*

Contributors can expedite reviewing and printing of their articles by doing these things:

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